Structure Dependent Thermal Conductivity of Reactively Sputtered ZnO Thin Films

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The in-plane and out-plane thermal conductivities of ZnO thin films, produced by reactive sputtering, have been measured at room temperature. As determined by transmission electronic microscopy observations on the cross-section of the films, each film consists of two layers: an interfacial layer immediately above the substrate, with thickness of about 200 nm and composed of needle-like crystal grains; and another layer above the interfacial layer, composed of column-shaped grains, aligned along the out-plane direction. The grain diameters at the top of the films range from 35 to 100 nm, depending on the oxygen content of the sputtering gas. The measured out-plane thermal conductivity, on samples with grain diameter of 100 nm, are 2.4 $Wm^{-1}K^{-1}$ and 7.0 $Wm^{-1}K^{-1}$, for the interfacial and the above layer respectively. The in-plane thermal conductivity varies from 2.7 to 6.0 $Wm^{-1}K^{-1}$, decreasing as the grain diameter decreases. The thermal conductivity of the column-structured ZnO has been analyzed by an effective media theory method, with consideration of the thermal resistance at the grain boundaries. The result shows that the main reason of the low thermal conductivity of the ZnO thin film can be attributed to the reduction in the intrinsic thermal conductivity of the ZnO crystals, which is a function of the grain diameter varying with the oxygen content of the sputtering gas.